Electric Field Gating with Ionic Liquids

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Electric field gating using doped silicon with its native oxide as the dielectric is central to the operation of many transistors used in present day electronics. In collaboration with the Rinzler group at the University of Florida, we have used ionic liquids to modulate the electrical and optical properties of thin films made from carbon nanotubes [1]. Here we show that similar techniques can be used to modulate the resistance of semi-transparent conducting indium oxide films. The use of an ionic liquid rather than a native oxide dielectric allows remarkably large field induced resistance changes that make this system highly promising for electro-optic applications.

[1] Z. Wu *et al.*, **Science** (in press, 2004)

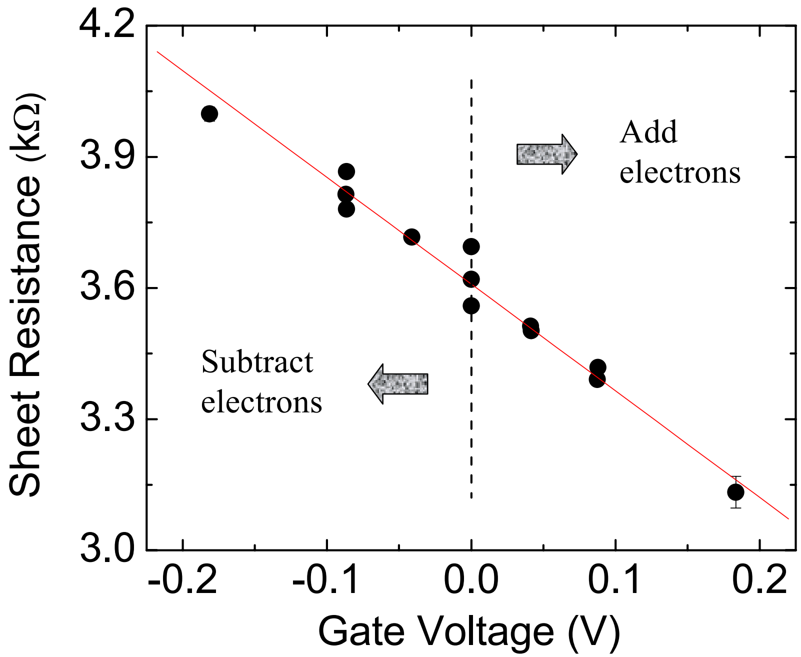

Figure: Plot of the resistance change for a 300 Å thick indium oxide film as a function of the gate voltage applied to a near lying metal electrode separated from the indium oxide film by an ionic liquid.

Field effect transistors (FETs) and related field gated devices play a dominant role in our present day electronic and optical technologies. The basic principle of operation can be understood by making an analogy with a planar trilayer capacitance structure in which the underlying base electrode (the film under study) is separated from an overlying gate electrode by an insulating dielectric thin-film spacer. By applying a positive voltage to the gate, a negative charge is induced on the film under study and the higher electron density will give rise to a resistance decrease. A positive voltage applied to the gate will remove electrons from the film under study and lead to an increase in resistance. Electrical resistance and optical transmission both depend on the density of charge carriers.

In analogy to silicon based FETs we have performed field gating experiments on thin semi-transparent films of carbon nanotubes and indium oxide, where the film separating the gate from the material under study is an ionic liquid rather than an oxide dielectric. The field gated changes in the electrical and optical properties of nanotube films using ionic liquids are reported in a paper soon to be published in Science [Z. Wu *et al.*, **Science** (in press, 2004)]. In this present report we extend these results and show (see Figure) the resistance changes that occur when a thin indium oxide film is gated in a similar manner. As expected, a positive gate electrode gives rise to an increased electron density and correspondingly lower resistance whereas a negative gate voltage causes the opposite effect. The observed resistance changes *are more than a factor of ten greater* than can be achieved using conventional oxide dielectrics on similar indium oxide films.We attribute this improved performance to the fact that ionic liquids are more efficient in creating a high surface charge density at thin film interfaces. Since indium oxide and related conducting transparent materials, such as indium tin oxide (ITO), are extensively used as electrodes for solar cells and displays, we anticipate that these studies will lead to new opportunities in electro-optic technologies.

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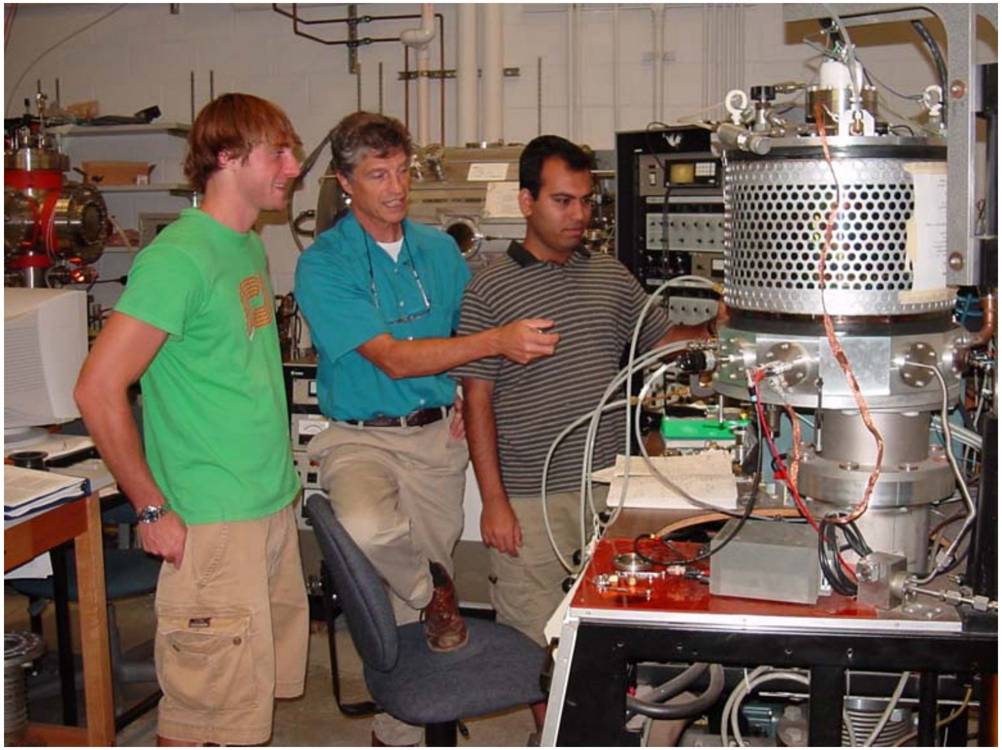
Education and Societal Impact:
This grant has supported two full-time graduate students (both graduated with PhD's), two part time graduate students, one part time postdoctoral associate and two undergraduates. The project reported here was initiated during the summer (2004) visit of REU student Chris Penley, an undergraduate physics major from Lenoir-Rhyne College in North Carolina. Chris worked closely with senior graduate student Partha Mitra. Their results show that, upon application of an electric field, ionic liquids are efficient in creating a high surface charge density at thin film interfaces and thus might prove useful in electro-optic applications.



The PI (center) flanked by REU student Chris Penley (foreground) and fifth year graduate student Partha Mitra (background) discussing the deposition of indium oxide thin films.